(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

AP

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 December 2004 (23.12.2004)

PCT

(10) International Publication Number
WO 2004/110265 A1

(51) International Patent Classification⁷: A61B 5/00

(21) International Application Number: PCT/SE2004/000907

(22) International Filing Date: 11 June 2004 (11.06.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0301718-3 13 June 2003 (13.06.2003) SE

(71) Applicant (*for all designated States except US*): **ATOS MEDICAL AB** [SE/SE]; Box 183, S-242 22 Hörby (SE).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **ÖBERG, Åke** [SE/SE]; Ugglebovägen 79, S-590 72 Ljungsbro (SE). **JOHANSSON, Anders** [SE/SE]; Platensgatan 32, S-582 20 Linköping (SE). **KNUTSSON, Hans** [SE/SE]; Egnahemsgatan 11, S-582 47 Linköping (SE). **BORGA, Magnus** [SE/SE]; Ringstorp, Jonsberg 1, S-585 94 Linköping (SE). **STRÖMBERG, Tomas** [SE/SE]; Allmogegatan 62, S-583 33 Linköping (SE). **SUNDBERG, Mikael** [SE/SE]; Djurgårdsgatan 37B, S-582 29 Linköping (SE).

(74) Agent: **HANSSON THYRESSON PATENTBYRÅ AB**; Box 73, S-201 20 Malmö (SE).

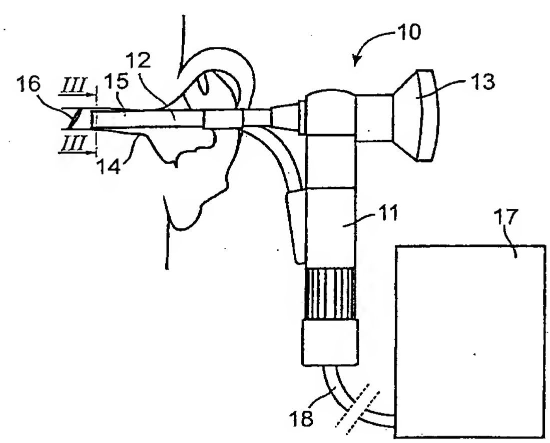
(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) **Title:** DEVICE FOR MEASURING PHYSICAL PROPERTIES OF THE TYMPANIC MEMBRANE



(57) **Abstract:** Device for measuring physical properties of the tympanic membrane (TM), comprising an elongated probe (12) with a distal end (15) for inspection of the ear, wherein a plurality of optical fibres is arranged in said elongated probe. The plurality of fibres includes either a first set of fibres (21) for conveying light from a light source to said distal end of said probe and a second set of fibres (22) for conveying light reflected from the tympanic membrane in front of said distal end to a first detector means (23) or a set of fibres both for conveying light from a light source to said distal end of said probe and for conveying light reflected from the tympanic membrane in front of said distal end to a first detector means (23). Said first detector means (23) is designed for measuring the intensity of light reflected from the tympanic membrane. Method for measuring physical properties of the tympanic membrane (TM), including the following steps: a) illuminating the tympanic membrane with light from a light source, b) detecting light reflected from the tympanic membrane, and c) analysing the intensity at selected wavelengths or a spectrum of wavelengths.

WO 2004/110265 A1

apply an erythema detection algorithm on the acquired data. A novel algorithm utilizes the fact that the photon absorption in the Q-band of various blood chromophores is different in erythymatous and in normal tissue.

A quantity, derived from the spectra, to be used for separating the states "erythematous tissue" and "normal tissue" that is independent of the geometrical distance between the probe head and site of measurement was desirable. For this reason the quotient

$$Q_\lambda = \frac{R_\lambda}{R_{650}} \qquad (1)$$

was used.

R_{650} and R_λ are the reflectivity at 650 nm and λ nm, respectively. Normalization was performed by dividing every sample in each spectrum with its reflectivity at 650 nm. A variety of λ:s were tested. λ:s were selected in the absorption peak of bilirubin and the Q-band of oxyhemoglobin (HbO_2) (460 nm, 542 nm and 576 nm). In addition, λ-values were chosen based on measurements of Q_λ in normal and erythematous TM,.in order to maximize discrimination. It was observed that Q_λ discriminated well at λ:s near 490 nm and 576 nm.

In accordance with the invention based on a two-wavelength or four-wavelength system the first detector means can include discrete detectors for each specific frequency. Each detector can be combined with a narrow filter, to achieve the desired frequency characteristics. Appropriate centre wavelengths are 460 nm, 490 nm, 542 nm, 576 nm and 650 nm. The detectors are connected to the signal processor 24 in the control apparatus 17. In such an embodiment the signal processor 24 can have a less complicated design.

In the embodiment shown in Fig. 2 a second light source 25 is also included. The second light source emits light that is directed towards the target tissue as a visual reference when the probe is positioned in the external

Signals from the first detector means 23 and the second detector means 28 are fed to the signal processor 24 forming part of an imaging system. The resolution of the generated images is highly dependent of the probe-surface distance and the numerical aperture (NA) of the fibers used. In one embodiment commercially available plastic fibers (NA = 0.5) are used. The fibers can be arranged in two linear arrays in the probe head (one detector array and one illumination array), c.f. Fig. 3 - Fig. 6.

An appropriate mathematical model stipulates diffusely reflected photon detection. For this reason Polaroid filters can be appended in front of both the detector fiber array and the illumination fiber array, perpendicularly, to avoid detection of specularly reflected photons (c.f. Fig. 7). An example of filters is shown with reference to Fig. 6. The illumination and detector fibers are arranged in parallel and equidistantly distributed linearly in the lateral direction.

The number of optical fibres in the third set 29 and the fourth set 30 of optical fibres can be different from what is shown in the drawings and do not have to be equal.

Experimental data from convex and concave polyacetal plastic surfaces are recorded in a first step. A mathematical model of the sensor can also be used for simulating images of the surfaces analysed. The detected image is compared in a second step with the recorded data and a shape associated to the recorded data that corresponds best to the detected image is selected. An estimate of the shape characteristics of a surface is extractable from the images generated by the system. In particular, the system distinguishes perfectly accurate between convex and concave surfaces; which, e.g. is important when characterizing the TM.

The control apparatus 17 also comprises a control unit 31 operatively connected to other units of the control apparatus, such as the signal processor 24 and a memory unit 46. Experimental data or data created from the mathematical model is also stored in the memory unit. The light sources are driven by a driver unit 32, which is operated by the control unit. Data, such as operating commands, can be fed in by an input device 33, such as a key-

mination and detection, respectively. Preferably the spacing between the two fibre arrays is small, that is about 500 μm.

A first alternative embodiment of the tip end is shown in Fig. 4. Also in this embodiment the fibres are gathered in two semicircular sections. A first section 36 holds the first set 21 of optical fibres that is used for illumination. The ocular channel 35 also is arranged in the first section 36.

In a second semicircular section 37 of the tip 15 the second set 22 of optical fibres is provided. The number of individual fibres is chosen so as to supply each of the detectors in the first detector means 23 with a sufficient amount of reflected light. Normally, at least five individual fibres are used for each detector and each detector frequency.

In contrast to the embodiment of Fig. 3 three composite arrays formed by the third set 29 of optical fibres and the fourth set 30 of optical fibres are used. The arrays are disposed in close relationship and hold in a central position the separate optical fibre 26 that conveys light for a visual reference when the probe is positioned in the external auditory canal.

In a second alternative embodiment as shown in Fig. 5 four composite arrays formed by the third set 29 of optical fibres and the fourth set 30 of optical fibres are used. The arrays are disposed as four sides of a rectangle. In the centre of each of the arrays a separate optical fibre 26 is provided. The plurality of optical fibres 26 is optional, one fibre 26 is sufficient in this embodiment. When arranging several optical fibres 26, for instance as shown in Fig. 5, each of the fibres 26 can be positioned to emit light at a different angle to the perpendicular of the probe end surface. By such an arrangement it is possible to determine the distance between the probe end and the measuring object, in this case the TM. The ocular channel 35 in this embodiment is arranged in the centre of the probe end.

Light from the third set of optical fibres 29 will illuminate the surface along a line, each of the light emitting diodes 27 being turned on at a time. The sequence in which the light emitting diodes 27 are illuminated can be circular queue, such as a Round Robin scheduling algorithm, starting with activating a first fibre in the third set of optical fibres, continuing with the sec-

Two separate optical fibres, or set of fibres, 26' arranged opposite each other are provided for facilitating the positioning of the probe head in the ear of a patient. In this embodiment the second light source 25 produces a collimated light that will be directed from the optical fibres 26' in two intersecting beams (c.f. Fig. 7). After intersecting the light beams will hit the tympanic membrane in two separate and distinctive positions. By adjusting the distance between the probe and the tympanic membrane until target areas of the light beams are located at opposite side edges of the tympanic membrane it is possible position the probe at an appropriate distance from the tympanic membrane.

On the right hand side of the probe head a plurality of channels are formed in two concentric lines. The channels in an inner line hold the third set of optical fibres 29 that are used for illuminating the tympanic membrane in the curvature recognition process. The channels in an outer line hold the fourth set of optical fibres 30 that are used for detecting the curvature of the tympanic membrane. The third set of optical fibres 29 is arranged and positioned to direct emitted light to a straight line on a flat surface. By illuminating each of the fibres in the third set of optical fibres 29 in sequence, for instance as described above, an image indicative of the curvature of the tympanic membrane can be obtained from the fourth set of optical fibres 30.

A first annular section, carrying the illuminating third set of optical fibres 29, is covered by a first polarisation filter 39 and a second annular section, carrying the fourth set of optical detection fibres 30 is covered by a second polarisation filter 40. The direction of polarisation of the first filter was rotated 90° relative to the second, to assure maximum attenuation of specularly reflected photons.

Fig. 7 shows a schematic view of a second embodiment of the instrument 41 in accordance with the invention. The instrument 41 is compact and comprises an integral probe 12. A vertical grip section 42 is also integral with the probe and a lens 43 replaces the eyepiece in the previous embodiment. The probe 12 is inserted in the external auditory canal 14 the ocular channel 35 provides a possibility for an operator of the instrument to observe through

terised by the radius of the curvature. In the convex case, the probe can be considered to be localised outside the sphere, and in the concave case inside the sphere. As an example of a surface curvature classification algorithm, the difference between the mean of the diagonal elements and the mean of the fifth off-diagonal elements of the image generated by the two-parallel-fibre-sensor can be used. In the convex case, the difference is positive; contrary from the concave case, where it is negative. For a plane surface the difference is zero or close to zero. The radius of curvature can be extracted by empirical or theoretical matching of the image generated by the sensor with images from the same class of surfaces (i.e. images of convex or concave surfaces with different curvature radii in the range of interest).

sensitivity at 650 nm and a second detector having a peak sensitivity at 576 nm.

5. Device in accordance with claim 4, wherein said first detector means (23) comprises at five separate detectors, a first detector having a peak sensitivity around 650 nm, a second detector having a peak sensitivity around 460 nm, a third detector having a peak sensitivity around 490 nm, a fourth detector having a peak sensitivity around 542 nm, and a fifth detector having a peak sensitivity around 576 nm.

6. Device in accordance with claim 1, wherein the plurality of fibres includes a first set of illumination fibres (29), each of said illumination fibres being connected in a first end to one of a plurality of individually controllable light sources (27), and a second set of detecting fibres (30), said second set of detecting fibres being connected in a first end to individual detectors (28), said first set of illumination fibres (29) and said second set of detecting fibres (30), wherein said individually controllable light sources (27) are connected to a control unit (31) arranged to switch on said individually controllable light sources (27) in a sequence and wherein said individual detectors (28) are connected to said signal processor (24) for conveying signals responsive to the intensity of incident light reflected from the tympanic membrane.

7. Device in accordance with claim 6 where first set of illumination fibres (29) and said second set of detecting fibres (30) are equidistantly distributed in two parallel or concentric arrays in the distal end (15), or where first set of illumination fibres (29) and said second set of detecting fibres (30) are interleaved at the distal end (15).

8. Device in accordance with claim 6, wherein said first set of illumination fibres (29) is arranged to direct emitted light in the form of a line on to a target surface.

14. Device in accordance with claim 1, wherein said probe (12) extends from a vertical grip section (11) and an eyepiece (13) is optically connected to an ocular channel extending through said probe (12).

15. Method for measuring physical properties of the tympanic membrane (TM), including the following steps:

16. Method in accordance with claim 14, also including the following steps:

a) illuminating in sequence individual spots distributed over the tympanic membrane,

b) detecting the intensity of light reflected from the spots of the tympanic membrane and

c) determining the shape of the tympanic membrane by comparing said detected intensities with stored intensities obtained from type bodies having different shapes.

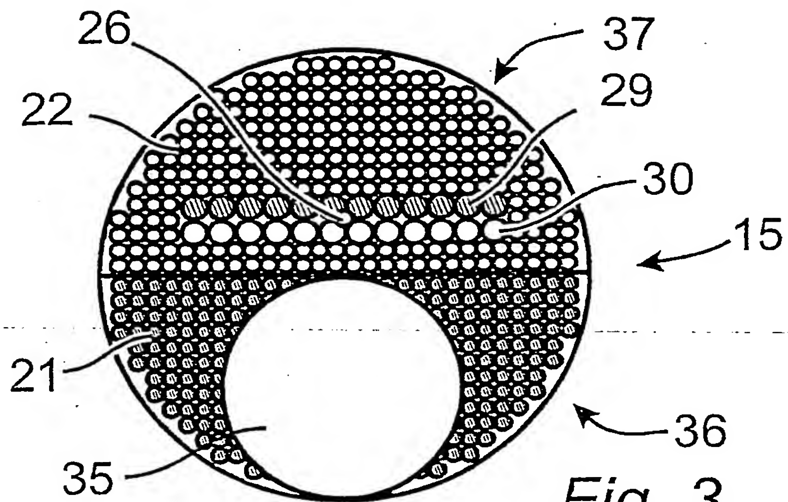


Fig. 3

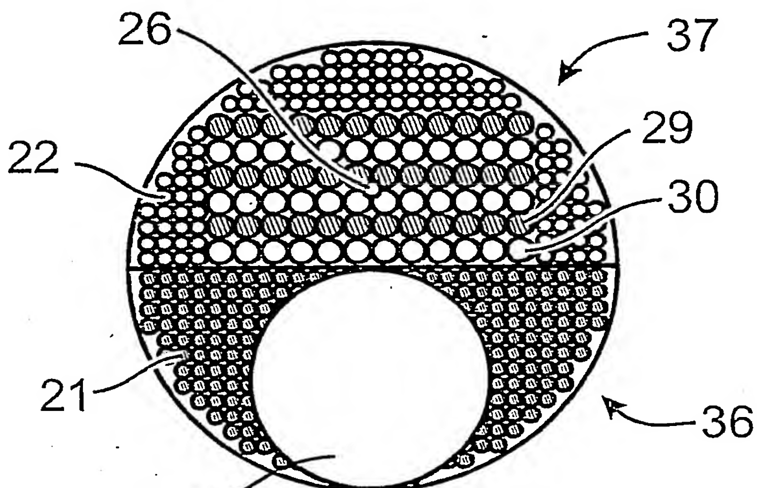


Fig. 4

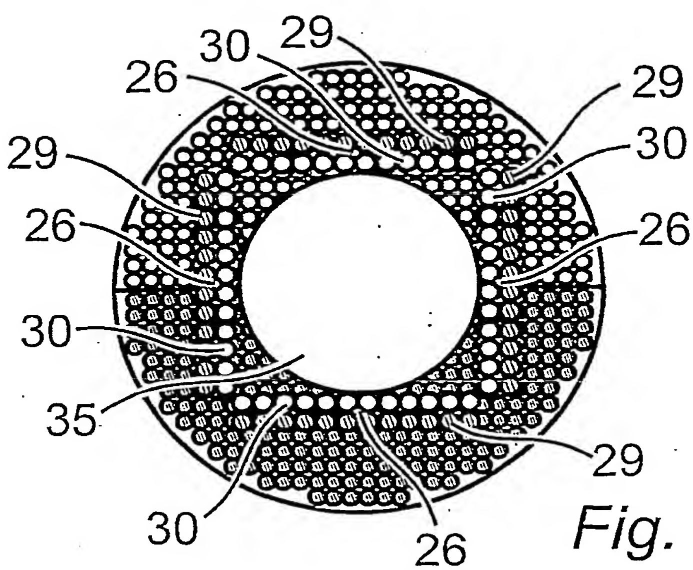


Fig. 5

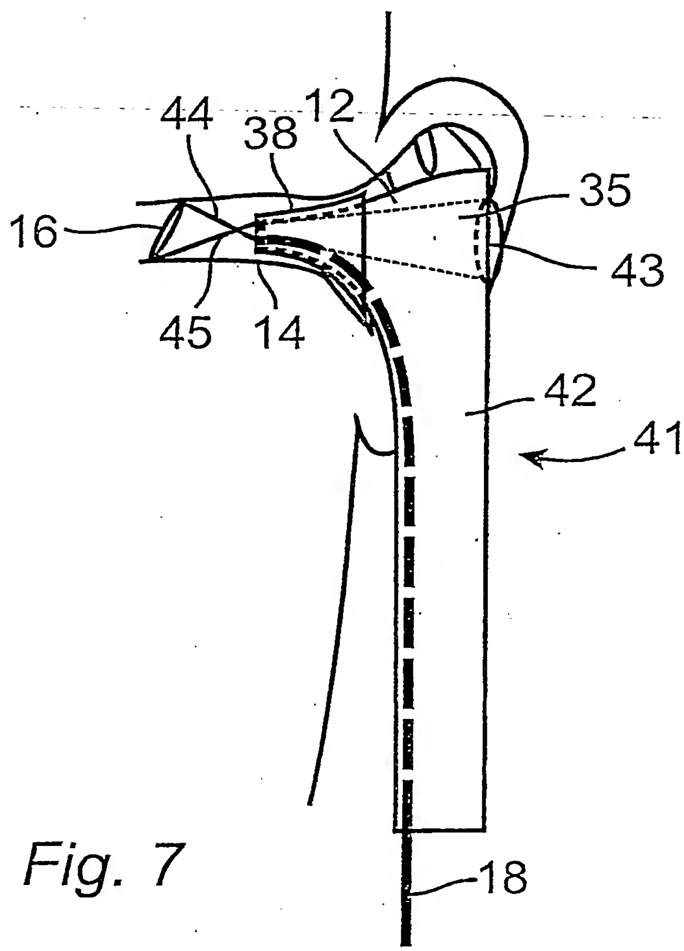


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 2004/000907

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: A61B 5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA, PAJ, INSPEC, BIOSIS, MEDLINE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	BIO-PHOTONICS `03: Program, Book of abstracts. Graduate summer school, Ven, Sweden, 15-21 June 2003, see page 16, Apendix --	1-14
X	US 5673692 A (SCHULZE, A.E. ET AL), 7 October 1997 (07.10.1997), column 3, line 60 - column 4, line 60, figures 1-12	1,4-8,10, 12-14
A	--	2,3,9,11

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 Sept 2004	28-09-2004

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Anna Malmberg/Els Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 2004/000907

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 15-16
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

see next page

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

03/09/2004

International application No.
PCT/SE 2004/000907

US	5673692	A	07/10/1997	NONE			
US	5115133	A	19/05/1992	AU	7789391	A	11/11/1991
				CA	2080472	A	20/10/1991
				EP	0525112	A	03/02/1993
				JP	5506171	T	16/09/1993
				US	5079421	A	07/01/1992
				US	5146091	A	08/09/1992
				US	5179951	A	19/01/1993
				WO	9115990	A	31/10/1991
US	6631288	B1	07/10/2003	AU	758971	B	03/04/2003
				AU	3977600	A	23/10/2000
				CA	2331451	A	12/10/2000
				CN	1306617	T	01/08/2001
				EP	1131630	A	12/09/2001
				GB	0008404	D	00/00/0000
				GB	2348699	A,B	11/10/2000
				GB	9907613	D	00/00/0000
				IL	139651	D	00/00/0000
				JP	2002540869	T	03/12/2002
				WO	0060349	A	12/10/2000
				ZA	200006569	A	13/02/2002
US	6450970	B1	17/09/2002	AU	1298701	A	30/05/2001
				WO	0135817	A	25/05/2001
US	6069689	A	30/05/2000	AU	7021198	A	11/11/1998
				US	6008889	A	28/12/1999
				WO	9846133	A	22/10/1998
US	5847832	A	08/12/1998	NONE			
US	5699809	A	23/12/1997	US	5868682	A	09/02/1999
				AT	229173	T	15/12/2002
				AU	699941	B	17/12/1998
				AU	4906796	A	14/08/1996
				BR	9606810	A	29/06/1999
				CA	2210518	A,C	01/08/1996
				CN	1089893	B	28/08/2002
				CN	1169774	A	07/01/1998
				DE	69625242	D,T	30/10/2003
				EP	0871850	A,B	21/10/1998
				ES	2188741	T	01/07/2003
				FI	973665	A	12/09/1997
				JP	11509105	T	17/08/1999
				KR	235170	B	15/12/1999
				NO	973417	A	26/09/1997
				NZ	302902	A	29/03/1999
				WO	9623293	A	01/08/1996